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(54) **VEHICLE STEERING SYSTEMS**

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B62D 3/00	(2006.01)
B62D 3/04	(2006.01)
B62D 3/06	(2006.01)

(52) **U.S. Cl.**

CPC .. ***B62D 5/18*** (2013.01); ***B62D 3/00*** (2013.01); ***B62D 3/04*** (2013.01); ***B62D 3/06*** (2013.01); ***B62D 5/062*** (2013.01)

(58) **Field of Classification Search**

CPC B62D 5/18; B62D 5/062; B62D 3/00
USPC 180/417, 426, 441; 280/773
See application file for complete search history.

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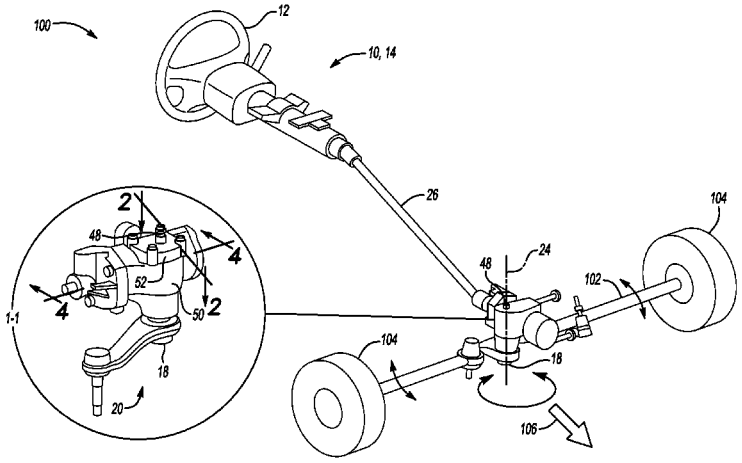
(57) **ABSTRACT**

A steering system for a vehicle includes a sector shaft defining a bore therein and rotatable about a central longitudinal axis. The steering system also includes a lash adjuster translatable within the bore along the central longitudinal axis. In addition, the steering system includes an end cap cover abutting the lash adjuster and spaced apart from the sector shaft to define a first cavity between the end cap cover and the sector shaft, and a housing abutting the end cap cover and spaced apart from the sector shaft to define a second cavity between the housing and the sector shaft. The steering system also includes a seal surrounding and abutting the sector shaft, wherein the seal separates the first cavity from the second cavity.

20 Claims, 4 Drawing Sheets



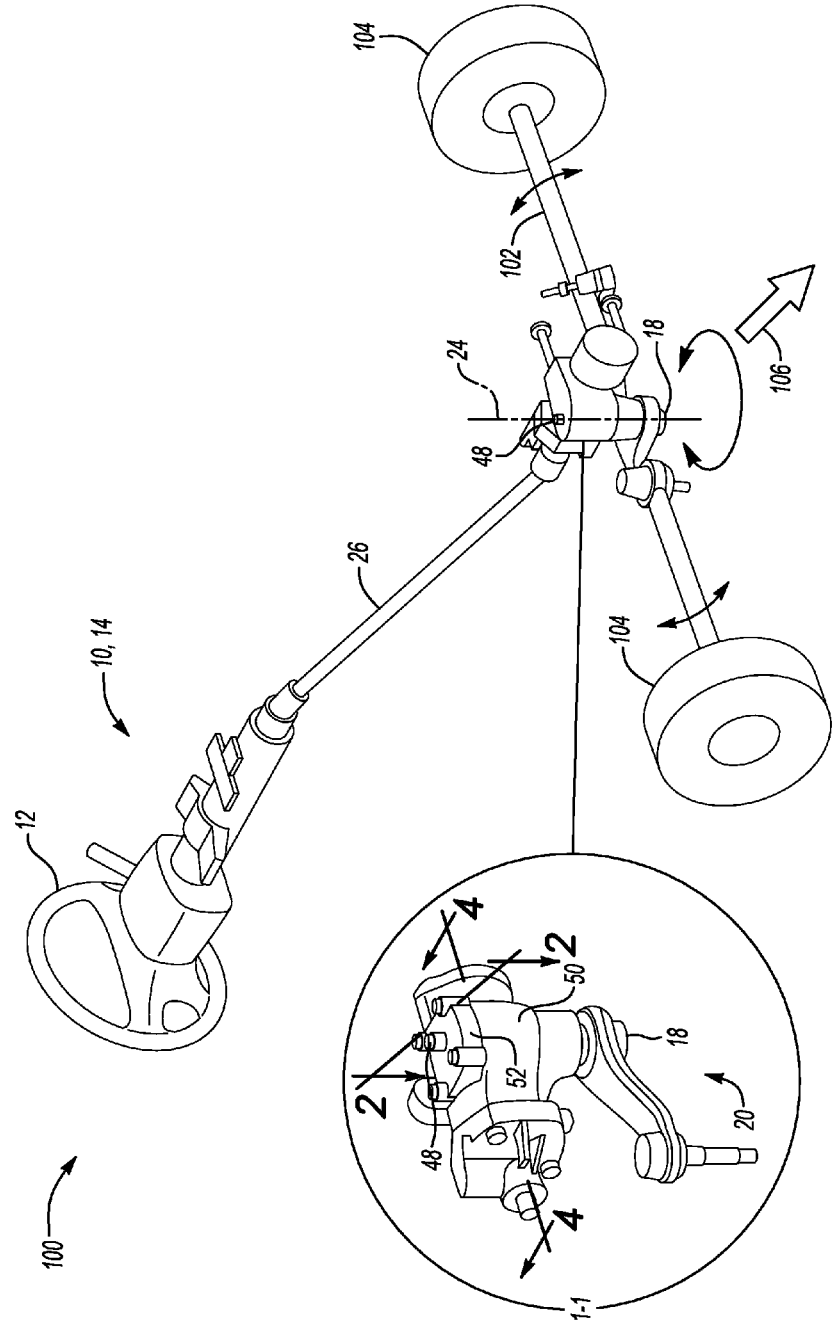


Fig-1

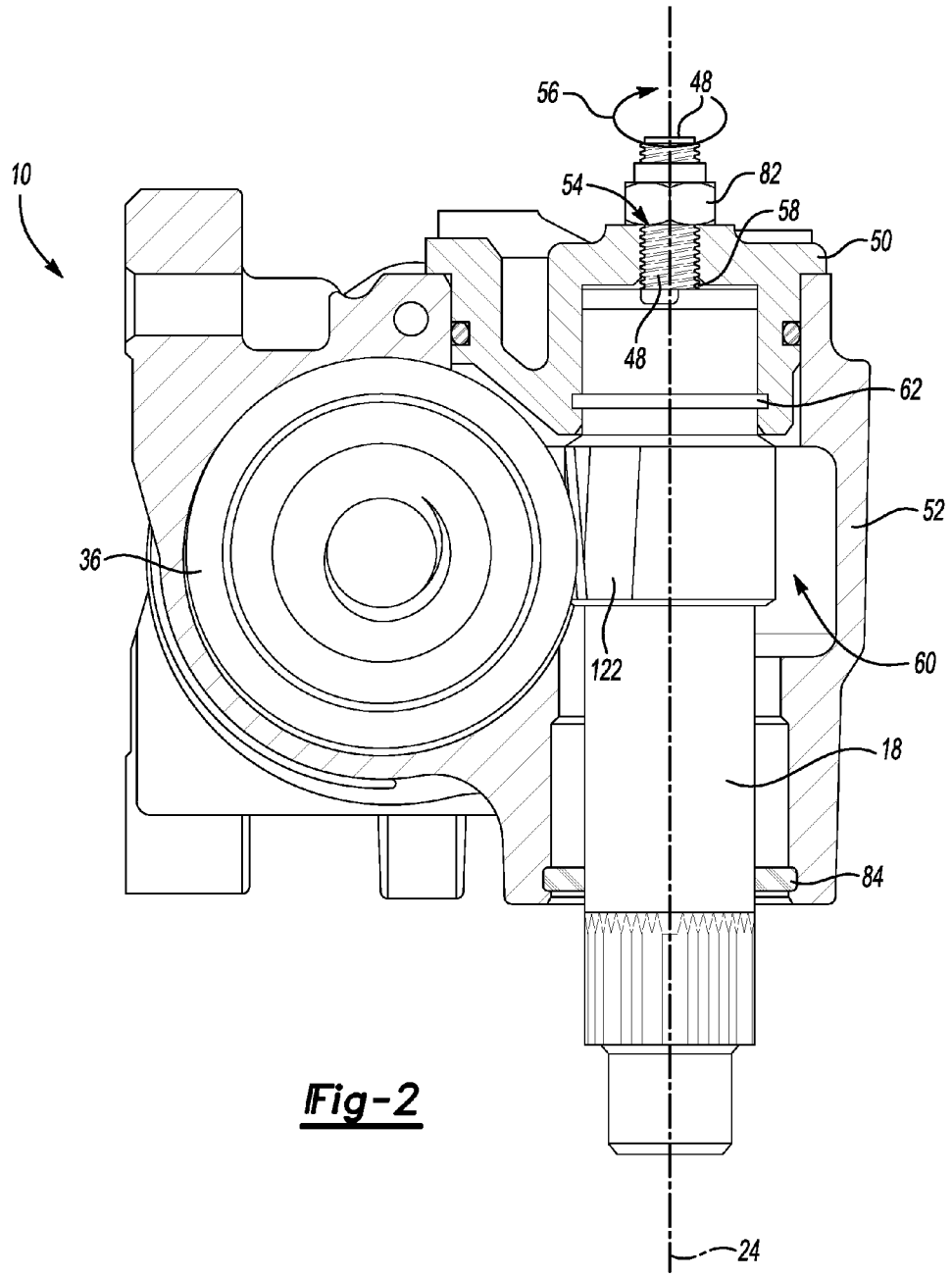


Fig-2

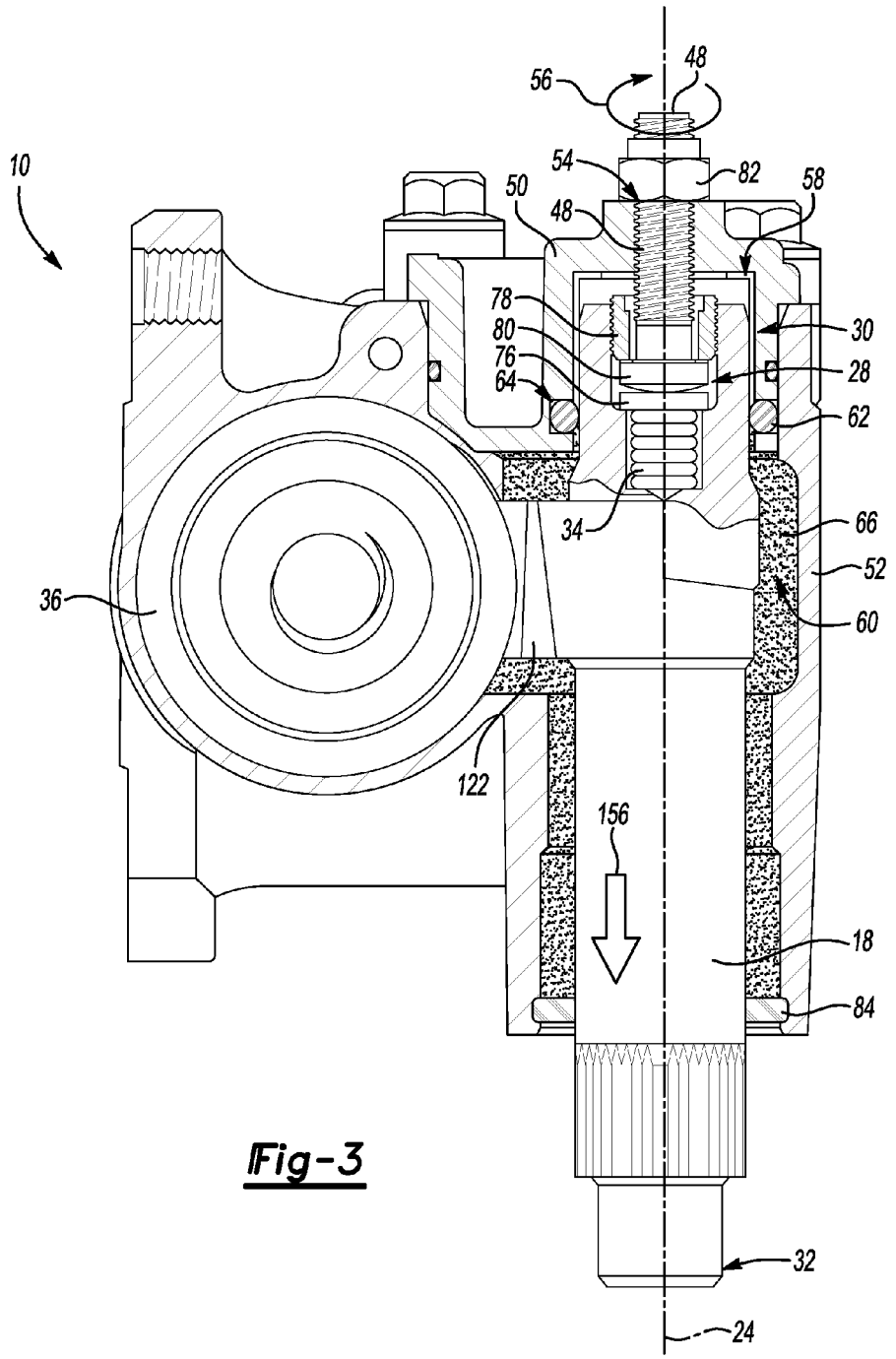

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Fig-3

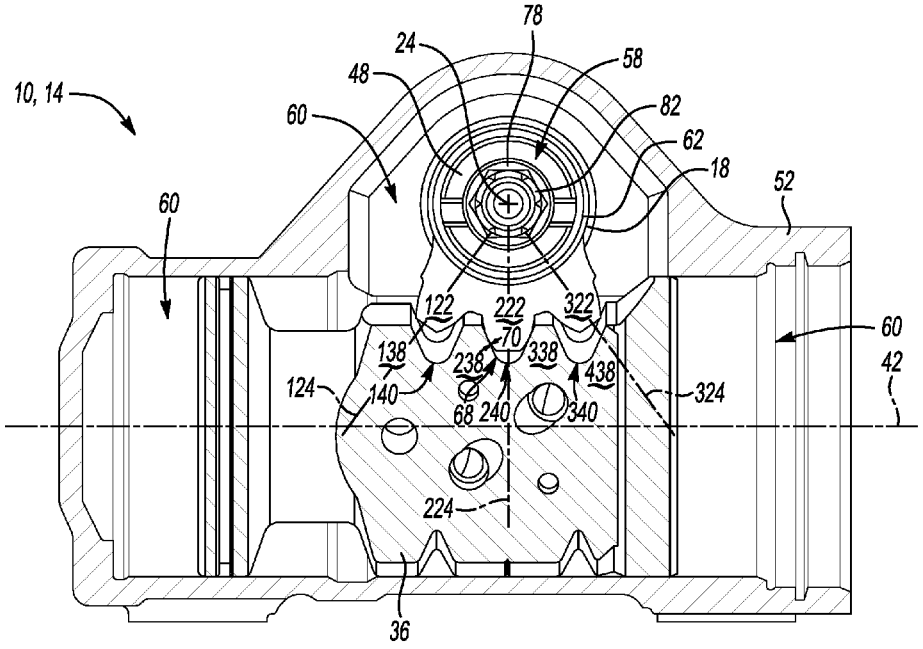
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Fig-4A

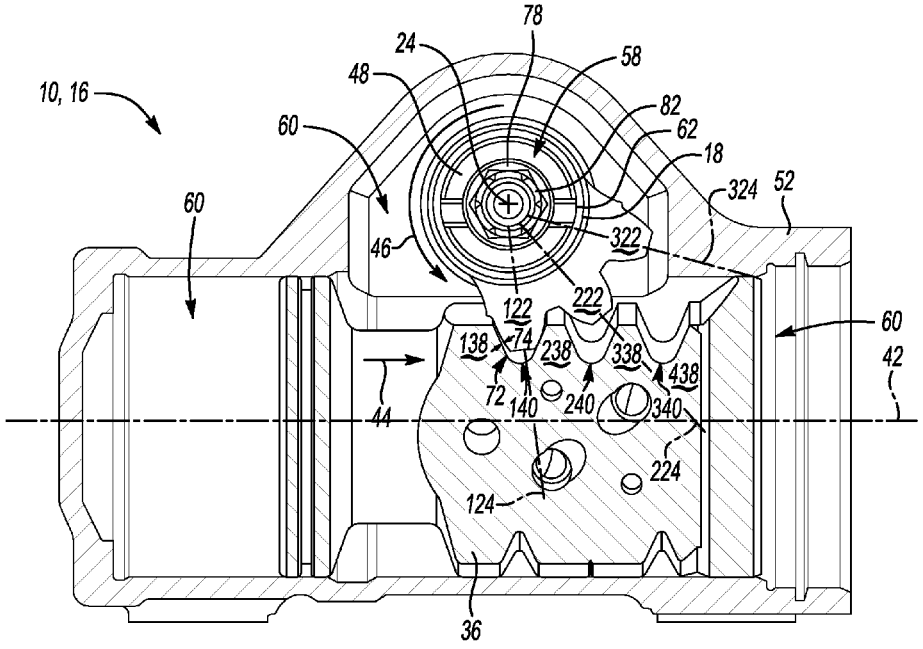
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Fig-4B

VEHICLE STEERING SYSTEMS

TECHNICAL FIELD

The disclosure relates to a steering system for a vehicle.

BACKGROUND

Steering systems for vehicles may include a sector shaft rotatable against a rack ball nut to thereby steer vehicle wheels in a desired direction. More specifically, a steering wheel of the vehicle may rotate between an on-center position and an off-center position and thereby rotate the sector shaft with respect to the rack ball nut via intermeshing gear teeth. As such, alignment of the sector shaft with respect to the rack ball nut contributes to the effectiveness and ease of operation of the steering system.

SUMMARY

A steering system for a vehicle includes a sector shaft defining a bore therein and rotatable about a central longitudinal axis. The steering system also includes a lash adjuster translatable within the bore along the central longitudinal axis. In addition, the steering system includes an end cap cover abutting the lash adjuster and spaced apart from the sector shaft to define a first cavity between the end cap cover and the sector shaft. Further, the steering system includes a housing abutting the end cap cover and spaced apart from the sector shaft to define a second cavity between the housing and the sector shaft. The steering system also includes a seal surrounding and abutting the sector shaft, wherein the seal separates the first cavity from the second cavity.

In another embodiment, a steering system for a vehicle includes a steering wheel rotatable between an on-center position and an off-center position, and a sector shaft having a plurality of gear teeth each protruding therefrom along a respective one of a plurality of gear axes. The sector shaft has a proximal end defining a bore therein and is rotatable about a central longitudinal axis that is substantially perpendicular to each of the plurality of gear axes as the steering wheel rotates between the on-center position and the off-center position. The steering system also includes a rack ball nut having a plurality of cogs extending therefrom and defining a plurality of grooves therebetween, wherein each of the plurality of gear teeth is matable with a respective one of the plurality of grooves. Further, the steering system includes a lash adjuster translatable within the bore along the central longitudinal axis. The steering system also includes an end cap cover abutting the lash adjuster and spaced apart from the sector shaft to define a first cavity between the end cap cover and the sector shaft. In addition, the steering system includes a housing abutting the end cap cover and spaced apart from the sector shaft to define a second cavity between the housing and the sector shaft. The steering system also includes a seal surrounding and abutting the sector shaft, wherein the seal separates the first cavity from the second cavity so that the first cavity is not disposed in fluid communication with the second cavity. Further, the steering system includes a fluid disposed in contact with the sector shaft and the rack ball nut within the second cavity. The fluid is not disposed within the first cavity and does not exert hydraulic pressure on the proximal end so that each of the plurality of gear teeth is spaced apart from a respective one of the plurality of cogs as the steering wheel rotates from the on-center position to the off-center position. A center one of the plurality of gear teeth meshes with a center one of the plurality of grooves to define a first gap having a first thickness between the center one of the plurality of gear teeth and one of the plurality of cogs when the steering wheel is disposed in the on-center position. An outer one of the plurality of gear teeth meshes with an outer one of the plurality of grooves to define a second gap having a second thickness that is greater than the first thickness between the outer one of the plurality of gear teeth and an outer one of the plurality of cogs when the steering wheel is disposed in the off-center position.

A vehicle includes an axle, and a plurality of wheels each rotatable about the axle. The vehicle also includes a steering system configured for pivoting the axle about a central longitudinal axis to thereby steer the plurality of wheels. The steering system includes a sector shaft defining a bore therein and rotatable about the central longitudinal axis. The steering system also includes a lash adjuster translatable within the bore along the central longitudinal axis. Further, the steering system includes an end cap cover abutting the lash adjuster and spaced apart from the sector shaft to define a first cavity between the end cap cover and the sector shaft. In addition, the steering system includes a housing abutting the end cap cover and spaced apart from the sector shaft to define a second cavity between the housing and the sector shaft. The steering system also includes a seal surrounding and abutting the sector shaft, wherein the seal separates the first cavity from the second cavity.

The above features and advantages and other features and advantages of the present invention will be readily apparent from the following detailed description of the preferred embodiments and best modes for carrying out the present invention when taken in connection with the accompanying drawings and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic perspective illustration of a vehicle including a steering system, wherein the steering system includes a steering wheel and an integral gear, shown enlarged at circle **1-1**, having a sector shaft and a rack ball nut;

FIG. **2** is a schematic illustration of a cross-sectional view of the sector shaft and rack ball nut of FIG. **1** taken along section lines **2-2**;

FIG. **3** is a schematic illustration of a cross-sectional and partially cut-away view of the sector shaft and rack ball nut of FIGS. **1** and **2**;

FIG. **4**A is a schematic illustration of a top cross-sectional view of the sector shaft and rack ball nut of FIGS. **1-3** taken along section lines **4-4**, wherein the sector shaft is disposed in an on-center position; and

FIG. **4**B is a schematic illustration of a top cross-sectional view of the sector shaft and rack ball nut of FIG. **4**A, wherein the sector shaft is disposed in an off-center position.

DETAILED DESCRIPTION

Referring to the Figures, wherein like reference numerals refer to like elements, a steering system **10** for a vehicle **100** is shown generally in FIG. **1**. The steering system **10** may be useful for vehicles **100**, such as automotive vehicles, that require precise and efficient steering without steering wheel play, vehicle drift, or vehicle wander during steering maneuvers. Therefore, the steering system **10** may also be useful for non-automotive vehicles, such as, but not limited to, recreational vehicles.

Referring now to FIG. **1**, the vehicle **100** includes an axle **102** and a plurality of wheels **104** each rotatable about the axle **102**. That is, the plurality of wheels **104** may rotate about the

axle **102** as the vehicle **100** travels in a desired direction **106**. The vehicle **100** also includes the steering system **10** configured for pivoting the axle **102** about a central longitudinal axis **24** to thereby steer the plurality of wheels **104** and change the direction **106** of travel of the vehicle **100**.

With continued reference to FIG. **1**, the steering system **10** may include a steering wheel **12** rotatable between an on-center position (shown generally at **14** in FIGS. **1** and **4**A) and an off-center position (shown generally at **16** in FIG. **4**B). That is, when disposed in the on-center position **14**, the steering wheel **12** may orient each of the plurality of wheels **104** of the vehicle **100** parallel to every other wheel **104** so that the vehicle **100** does not turn, but rather travels along a straight path. Conversely, when disposed in the off-center position **16**, the steering wheel **12** may turn the front wheels **104** of the vehicle **100** with respect to the rear wheels (not shown) of the vehicle **100** so that the vehicle **100** may steer through a left- or right-hand turn.

With continued reference to FIG. **1**, the steering system **10** includes a sector shaft **18**. The sector shaft **18** may be characterized as a Pitman shaft, and the steering system **10** may be generally characterized as a Pitman power steering system, as opposed to a rack and pinion power steering system (not shown). Further, the sector shaft **18** may be a component of an integral gear, which is shown enlarged at **20** in circle **1-1** of FIG. **1**.

As best shown in FIGS. **4**A and **4**B, the sector shaft **18** may have a plurality of gear teeth **122**, **222**, **322** each protruding therefrom along a respective one of a plurality of gear axes **124**, **224**, **324**. Although the sector shaft **18** may have any number of gear teeth **122**, in one non-limiting example, the sector shaft **18** may have three gear teeth **122**, **222**, **322** each protruding therefrom along a respective one of three gear axes **124**, **224**, **324**. Further, as best shown in FIG. **2**, the sector shaft **18** is rotatable about the central longitudinal axis **24** that is substantially perpendicular to each of the plurality of gear axes **124**, **224**, **324** as the steering wheel **12** (FIG. **1**) rotates between the on-center position **14** (FIG. **4**A) and the off-center position **16** (FIG. **4**B). That is, referring to FIG. **1**, the sector shaft **18** may be operatively connected to the steering wheel **12** via one or more steering linkages **26** or components and may rotate about the central longitudinal axis **24** when the steering wheel **12** is turned from the on-center position **14** to the off-center position **16**.

Referring now to FIG. **3**, the sector shaft **18** defines a bore **28** therein. More specifically, the sector shaft **18** may have a proximal end **30** defining the bore **28** therein, and a distal end **32** spaced apart from the proximal end **30** along the central longitudinal axis **24**. The bore **28** may be configured for receiving a resilient member **34**, as set forth in more detail below. Further, as set forth above, in one non-limiting example, the sector shaft **18** may include three gear teeth **122**, **222**, **322** (FIGS. **4**A and **4**B) each protruding from the proximal end **30** along a respective one of the plurality of gear axes **124**, **224**, **324** (FIGS. **4**A and **4**B).

Referring now to FIGS. **4**A and **4**B, the steering system **10** may also include a rack ball nut **36** having a plurality of cogs **138**, **238**, **338**, **438** extending therefrom and defining a plurality of grooves **140**, **240**, **340** therebetween, wherein each of the plurality of gear teeth **122**, **222**, **322** is matable with a respective one of the plurality of grooves **140**, **240**, **340**. Although the rack ball nut **36** may have any number of cogs **138**, in one non-limiting example, the rack ball nut **36** may have four cogs **138**, **238**, **338**, **438** extending therefrom and may define three grooves **140**, **240**, **340** therebetween. Therefore, each of the three gear teeth **122**, **222**, **322** may mate or mesh with a respective one of the plurality of three grooves **140**, **240**, **340** as the steering wheel **12** (FIG. **1**) rotates between the on-center position **14** (FIG. **4**A) and the off-center position **16** (FIG. **4**B). More specifically, the steering wheel **12** may rotate between the on-center position **14** and the off-center position **16** to translate the rack ball nut **36** along an axis **42** that is substantially perpendicular to the central longitudinal axis **24**, and thereby rotate the sector shaft **18** about the central longitudinal axis **24**. That is, as best shown in FIG. **4**B, the rack ball nut **36** may translate along the axis **42** in the direction of arrow **44** and thereby rotate the sector shaft **18** about the central longitudinal axis **24** in the direction of arrow **46**.

Referring now to FIG. **2**, the steering system **10** also includes a lash adjuster **48** translatable within the bore **28** (FIG. **3**) along the central longitudinal axis **24**. As set forth in more detail below, the lash adjuster **48** may be configured for minimizing lash between the plurality of gear teeth **122**, **222**, **322** (FIG. **4**A) and the plurality of cogs **138**, **238**, **338**, **438** (FIG. **4**A) when the steering wheel **12** (FIG. **1**) is disposed in the on-center position **14** (FIG. **4**A). As used herein, the terminology "lash" describes any spacing or tolerance between a gear tooth **122** and a respective one **138** of the plurality of cogs **138**, **238**, **338**, **438**. That is, lash describes a condition in which a space exists between the faces of meshing gear teeth **122**, **222**, **322** and cogs **138**, **238**, **338**, **438**, i.e., in which the gear tooth **122** does not mesh with a respective one **138** of the plurality of cogs **138**, **238**, **338**, **438** via an exact interference fit. Such lash requires additional wasted work input, e.g., turning the steering wheel **12** an additional number of degrees, to bring the gear teeth **122**, **222**, **322** and cogs **138**, **238**, **338**, **438** into contact when changing direction **106** (FIG. **1**) of the vehicle **100** (FIG. **1**). The additional wasted work input may be described as unloaded rotation of the steering wheel **12** upon changing vehicle direction **106** or trying to maintain straight-line steering when the steering wheel **12** is disposed in the on-center position **14** (FIG. **4**A). Lash may be felt by an operator of the vehicle **100** as imprecise steering, vehicle wander, vehicle pull or lead, lack of steering response, steering wheel play, and/or steering vagueness when the steering wheel **12** is disposed in the on-center position **14**. As such, lash may be undesirable when the steering wheel **12** is disposed in the on-center position **14**, and may be minimized by contact between the gear tooth **222** and the respective one **238**, **338** of the plurality of cogs **138**, **238**, **338**, **438** when the steering wheel **12** is disposed in the on-center position **14**.

Referring again to FIG. **2**, the steering system **10** further includes an end cap cover **50** and a housing **52**. The end cap cover **50** may be bolted to the housing **52** of the integral gear **20** (FIG. **1**) and as such, may be stationary or fixed with respect to the sector shaft **18** and the rack ball nut **36**. Stated differently, the end cap cover **50** may not be rotatable about the central longitudinal axis **24**. Further, the end cap cover **50** abuts the lash adjuster **48**. In particular, the lash adjuster **48** may be inserted into an aperture **54** defined by the end cap cover **50** and may, for example, be threadably mated to the end cap cover **50** such that rotation of the lash adjuster **48** may compress the resilient member **34** (FIG. **3**) along the central longitudinal axis **24**. More specifically, the lash adjuster **48** may be rotatable with respect to the end cap cover **50**, e.g., in a direction indicated by arrow **56**, to translate the resilient member **34** along the central longitudinal axis **24** away from the proximal end **30** (FIG. **3**), e.g., in a direction towards the distal end **32** (FIG. **3**) as indicated by arrow **156** (FIG. **3**).

Further, as best shown in FIG. **3**, the end cap cover **50** is spaced apart from the sector shaft **18** to define a first cavity **58** between the end cap cover **50** and the sector shaft **18**. Simi-

larly, the housing **52** abuts the end cap cover **50** and is spaced apart from the sector shaft **18** to define a second cavity **60** between the housing **52** and the sector shaft **18**.

As described with continued reference to FIG. **3**, the steering system **10** also includes a seal **62** surrounding and abutting the sector shaft **18**. For example, the end cap cover **50** may define an annular channel **64** therein, and the seal **62** may be disposed within the annular channel **64**. More specifically, the seal **62** may be disposed at the proximal end **30** of the sector shaft between the first cavity **58** and the second cavity **60**. As such, the seal **62** separates the first cavity **58** from the second cavity **60** so that the first cavity **58** is not disposed in fluid communication with the second cavity **60**. The seal **62** may be formed from any material suitable for separating the first cavity **58** from the second cavity **60**, e.g., an elastomer, and the seal **62** may be configured as a compressive O-ring.

In addition, as likewise shown in FIG. **3**, the steering system **10** may also include a gasket **84** disposed at the distal end **32** of the sector shaft **18**. More specifically, the gasket **84** may abut the sector shaft **18** to isolate the second cavity **60** from the ambient atmosphere external to the housing **52**. That is, the gasket **84** may be configured to prevent fluid communication between the second cavity **60** and the ambient atmosphere. The gasket **84** may be formed from any material suitable for separating the second cavity **60** from the ambient atmosphere, e.g., an elastomer, and the gasket **84** may also be configured as a compressive O-ring.

Therefore, as best shown in FIG. **3**, the steering system **10** may also include a fluid **66** disposed in contact with the sector shaft **18** within the second cavity **60**. As such, the fluid **66** may also be disposed in contact with the rack ball nut **36** within the second cavity **60**, and may be contained within the second cavity **60** by the seal **62** and the gasket **84**. The fluid **66** may be a lubricating fluid, such as, for example, a hydraulic fluid or a valve fluid. In operation, the fluid **66** may lubricate moving components of the steering system **10** within the second cavity **60**, e.g., the plurality of gear teeth **122**, **222**, **322** (FIGS. **4**A and **4**B) of the sector shaft **18** and elements of the rack ball nut **36**. However, the fluid **66** may not be disposed within the first cavity **58**. That is, the seal **62** separates the first cavity **58** from the second cavity **60** so that the fluid **66** may not flow from the second cavity **60** to the first cavity **58**. In particular, the fluid **66** may not be disposed within the first cavity **58** when the steering wheel **12** (FIG. **1**) is disposed in the on-center position **14** (FIG. **4**A), and the fluid **66** may not be disposed within the first cavity **58** when the steering wheel **12** is disposed in the off-center position **16** (FIG. **4**B). As such, the fluid **66** may not exert hydraulic pressure on the proximal end **30**. That is, the fluid **66** may not force the sector shaft **18** to translate in a direction of arrow **156** during operation of the steering system **10**.

Referring again to FIG. **3**, the fluid **66** may not be flowable from the second cavity **60** to the first cavity **58** so that each of the plurality of gear teeth **122**, **222**, **322** (FIGS. **4**A and **4**B) is spaced apart from a respective one of the plurality of cogs **138**, **238**, **338**, **438** (FIGS. **4**A and **4**B) as the steering wheel **12** (FIG. **1**) rotates from the on-center position **14** (FIG. **4**A) to the off-center position **16** (FIG. **4**B). Further, the fluid **66** may not be flowable from the second cavity **60** to the first cavity **58** so that the center one **222** (FIG. **4**A) of the plurality of gear teeth **122**, **222**, **322** meshes with the center one **240** (FIG. **4**A) of the plurality of grooves **140**, **240**, **340** as the steering wheel **12** rotates from the off-center position **16** to the on-center position **14**.

That is, referring now to FIGS. **4**A and **4**B, in operation, the center one **222** of the plurality of gear teeth **122**, **222**, **322** may mesh with the center one **240** of the plurality of grooves **140**, **240**, **340** to define a first gap **68** (FIG. **4**A) having a first thickness **70** (FIG. **4**A) between the center one **222** of the plurality of gear teeth **122**, **222**, **322** and one **238** of the plurality of cogs **138**, **238**, **338**, **438** when the steering wheel **12** (FIG. **1**) is disposed in the on-center position **14** (FIG. **4**A). That is, the first thickness **70** may correspond to lash between the center one **222** of the plurality of gear teeth **122**, **222**, **322** and one **238** of the plurality of cogs **138**, **238**, **338**, **438**, and may be minimized by the steering system **10**.

Further, referring to FIG. **4**B, during operation of the steering system **10**, the outer one **122** of the plurality of gear teeth **122**, **222**, **322** may mesh with the outer one **140** of the plurality of grooves **140**, **240**, **340** to define a second gap **72** having a second thickness **74** that is greater than the first thickness **70** (FIG. **4**A) between the outer one **122** of the plurality of gear teeth **122**, **222**, **322** and the outer one **138** of the plurality of cogs **138**, **238**, **338**, **438** when the steering wheel **12** (FIG. **1**) is disposed in the off-center position **16**. That is, the second thickness **74** may correspond to lash between the outer one **122** of the plurality of gear teeth **122**, **222**, **322** and the outer one **138** of the plurality of cogs **138**, **238**, **338**, **438**, and may be maintained, e.g., may not be minimized, by the steering system **10**.

More specifically, as best shown in FIG. **3**, the steering system **10** may also include the resilient member **34**, e.g., a coil spring, disposed within the bore **28** of the sector shaft **18**, and a washer **76** sandwiched between the resilient member **34** and the lash adjuster **48**. That is, the lash adjuster **48** may be configured as a threaded bolt, and may compress the resilient member **34** and thereby decrease lash between the gear teeth **122**, **222**, **322** (FIGS. **4**A and **4**B) and cogs **138**, **238**, **338**, **438** (FIGS. **4**A and **4**B) when the steering wheel **12** (FIG. **1**) is disposed in the on-center position **14** (FIG. **4**A), as set forth in more detail below.

With continued reference to FIG. **3**, the steering system **10** may further include a retainer **78** disposed within the bore **28** and threadably mated to the lash adjuster **48** and configured for positioning the sector shaft **18** along the central longitudinal axis **24** as the steering wheel **12** (FIG. **1**) rotates between the on-center position **14** (FIG. **4**A) and the off-center position **16** (FIG. **4**B). The retainer **78** may be disposed in contact with the sector shaft **18** at the proximal end **30**, but may not rotate about the central longitudinal axis **24** as the sector shaft **18** rotates about the central longitudinal axis **24**. Further, as best shown in FIG. **3**, the lash adjuster **48** may have an annular shoulder **80** disposed in contact with the retainer **78**, and the lash adjuster **48** may be rotatable with respect to the retainer **78**.

In addition, referring to FIGS. **2** and **3**, the steering system **10** may further include a nut **82** threadably matable with the lash adjuster **48** and abuttable with the end cap cover **50**. That is, the nut **82** may be configured to retain the lash adjuster **48** within the aperture **54** along the central longitudinal axis **24**. Therefore, rotation of the lash adjuster **48** may compress the resilient member **34** along the central longitudinal axis **24**. More specifically, the lash adjuster **48** may be rotatable with respect to the end cap cover **50**, e.g., in a direction indicated by arrow **56**, to translate the washer **76** along the central longitudinal axis **24** towards the distal end **32**, compress the resilient member **34** in the direction of arrow **156** (FIG. **3**), and thereby decrease the first thickness **70** (FIG. **4**).

In further detail, as described with continued reference to FIGS. **4**A and **4**B, the nut **82** may position the sector shaft **18** along the central longitudinal axis **24** with respect to the end cap cover **50**, and thereby space each of the plurality of gear teeth **122**, **222**, **322** away from a respective one of the plurality of cogs **138**, **238**, **338**, **438** as the steering wheel **12** (FIG. **1**)

rotates from the on-center position **14** (FIG. **4**A) to the off-center position **16** (FIG. **4**B). That is, the lash adjuster **48** may be positioned so that each of the plurality of gear teeth **122**, **222**, **322** moves away from a respective one of the plurality of cogs **138**, **238**, **338**, **438** to maintain the second thickness **74** (FIG. **4**B). Therefore, the steering system **10** (FIG. **1**) may maintain the second thickness **74** or lash between the outer gear tooth **122** and the outer cog **138** when the steering wheel **12** is disposed in the off-center position **16**. Such lash or second gap **72** may subsequently assist an operator in turning the steering wheel **12** to again return the steering wheel **12** from the off-center position **16** to the on-center position **14**. That is, because the steering system **10** maintains the second gap **72** (FIG. **4**B), the plurality of gear teeth **122**, **222**, **322** may not bind up with respect to the plurality of cogs **138**, **238**, **338**, **438** when the steering wheel **12** is rotated from the off-center position **16**.

Conversely, with continued reference to FIGS. **4**A and **4**B, the lash adjuster **48** may also position the sector shaft **18** along the central longitudinal axis **24** with respect to the end cap cover **50**, and thereby translate each of the plurality of gear teeth **122**, **222**, **322** towards the respective one of the plurality of cogs **138**, **238**, **338**, **438** (FIG. **4**A) as the steering wheel **12** (FIG. **1**) rotates from the off-center position **16** (FIG. **4**B) to the on-center position **14** (FIG. **4**A). That is, each of the plurality of gear teeth **122**, **222**, **322** may move toward a respective one of the plurality of cogs **138**, **238**, **338**, **438** to minimize the first thickness **70** (FIG. **4**A). Therefore, the steering system **10** minimizes the first thickness **70** or lash between the center gear tooth **222** and the respective one **238** of the plurality of cogs **138**, **238**, **338**, **438** when the steering wheel **12** is disposed in the on-center position **14**. As such, the steering system **10** provides precise, substantially lash-free steering when the steering wheel **12** is disposed in the on-center position **14**.

Stated differently, referring to FIGS. **2**-**4**B, the nut **82**, the end cap cover **50**, the seal **62** (FIGS. **2** and **3**), the lash adjuster **48**, and the resilient member **34** (FIG. **3**) may together suspend the sector shaft **18** along the central longitudinal axis **24** adjacent to the plurality of cogs **138**, **238**, **338**, **438** (FIGS. **4**A and **4**B) to thereby minimize the first thickness **70** (FIG. **4**A) when the steering wheel **12** (FIG. **1**) is disposed in the on-center position **14** (FIGS. **1** and **4**A), and may maintain the second thickness **74** (FIG. **4**B) when the steering wheel **12** is disposed in the off-center position **16** (FIG. **4**B). That is, as the nut **82** is turned, the lash adjuster **48** may compress the resilient member **34** so that the sector shaft **18** drops slightly and the center one **222** of the plurality of gear teeth **122**, **222**, **322** contacts the respective one **138**, **238** of the plurality of cogs **138**, **238**, **338**, **438** when the steering wheel **12** is disposed in the on-center position **14**. Further, the seal **62** may ensure that no hydraulic pressure is exerted on the proximal end **30** of the sector shaft **18** in the direction of arrow **156** so that the sector shaft **18** may not drop along the central longitudinal axis **24** any further than specified by the position of the nut **82** and the lash adjuster **48**. Therefore, the resilient member **34**, the nut **82**, the end cap cover **50**, and the lash adjuster **48** may together properly position the sector shaft **18** along the central longitudinal axis **24** to minimize the first thickness **70** (FIG. **4**B).

As further described with reference to FIGS. **4**A and **4**B, for the aforementioned embodiment including three gear teeth **122**, **222**, **322** protruding from the sector shaft **18** and four cogs **138**, **238**, **338**, **438** protruding from the rack ball nut **36**, when the steering wheel **12** (FIG. **1**) is disposed in the on-center position **14** (FIG. **4**A), the center one **222** of the three gear teeth **122**, **222**, **322** may mesh with the center one **240** of the three grooves **140**, **240**, **340** to define the first gap **68** (FIG. **4**A) having the first thickness **70** (FIG. **4**A) between the center one **222** of the three gear teeth **122**, **222**, **322** and one **238** of the four cogs **138**, **238**, **338**, **438**. However, when the steering wheel **12** is disposed in the off-center position **16** (FIG. **4**B), the outer one **122** of the three gear teeth **122**, **222**, **322** may mesh with the outer one **140** of the three grooves **140**, **240**, **340** to define the second gap **72** (FIG. **4**B) having the second thickness **74** (FIG. **4**B) that is greater than the first thickness **70** between the outer one **122** of the three gear teeth **122**, **222**, **322** and the outer one **138** of the four cogs **138**, **238**, **338**, **438**.

Further, as described with continued reference to FIGS. **4**A and **4**B, the seal **62** separates the first cavity **58** from the second cavity **60** to ensure that the fluid **66** (FIG. **3**) does not force the sector shaft **18** in the direction of arrow **156** (FIG. **3**) as the steering wheel **12** (FIG. **1**) rotates from the on-center position **14** (FIG. **4**A) to the off-center position **16** (FIG. **4**B). As such, each of the three gear teeth **122**, **222**, **322** may be properly spaced away from the respective one of the four cogs **138**, **238**, **338**, **438** as the steering wheel **12** rotates from the on-center position **14** to the off-center position **16**. Subsequently, when a steering maneuver is complete, the seal **62** may also ensure that each of the three gear teeth **122**, **222**, **322** translates towards the respective one of the four cogs **138**, **238**, **338**, **438** as the steering wheel **12** rotates from the off-center position **16** to the on-center position **14**. Further, the seal **62** may ensure that the sector shaft **18** may not drop along the central longitudinal axis **24** in the direction of arrow **156** (FIG. **3**) away from the end cap cover **50** as the steering wheel **12** rotates from the off-center position **16** to the on-center position **14** to thereby minimize the first thickness **70** (FIG. **4**A) and any lash perceived by a vehicle operator during on-center steering.

Therefore, the steering system **10** (FIG. **1**) provides precise and efficient steering whether the steering wheel **12** (FIG. **1**) is disposed in the on-center position **14** (FIG. **4**A) or the off-center position **16** (FIG. **4**B). That is, the steering system **10** maintains the sector shaft **18** in a desired vertical position along the central longitudinal axis **24** and provides for substantially lash-free on-center steering. Even as continuous cycling of the steering wheel **12** between the on-center position **14** and the off-center position **16** may wear the plurality of gear teeth **122**, **222**, **322** (FIGS. **4**A and **4**B) and/or the plurality of cogs **138**, **238**, **338**, **438** (FIGS. **4**A and **4**B), the sector shaft **18** may continually align to the desired vertical position along the central longitudinal axis **24**. Therefore, even at end-of-life operating conditions, an interface between the plurality of gear teeth **122**, **222**, **322** and plurality of cogs **138**, **238**, **338**, **438** is substantially lash-free when the steering wheel **12** is disposed in the on-center position **14**.

While the best modes for carrying out the disclosure have been described in detail, those familiar with the art to which this disclosure relates will recognize various alternative designs and embodiments for practicing the disclosure within the scope of the appended claims.

The invention claimed is:

1. A steering system for a vehicle, the steering system comprising:

a steering wheel rotatable between an on-center position and an off-center position;

a sector shaft having a plurality of gear teeth each protruding therefrom along a respective one of a plurality of gear axes, wherein the sector shaft has a proximal end defining a bore therein and is rotatable about a central longitudinal axis that is substantially perpendicular to

each of the plurality of gear axes as the steering wheel rotates between the on-center position and the off-center position;

a rack ball nut having a plurality of cogs extending therefrom and defining a plurality of grooves therebetween, wherein each of the plurality of gear teeth is matable with a respective one of the plurality of grooves;

a lash adjuster translatable within the bore along the central longitudinal axis;

a resilient member disposed within the bore;

a washer sandwiched between the resilient member and the lash adjuster;

an end cap cover abutting the lash adjuster and spaced apart from the sector shaft to define a first cavity between the end cap cover and the sector shaft;

a housing abutting the end cap cover and spaced apart from the sector shaft to define a second cavity between the housing and the sector shaft;

a seal surrounding and abutting the sector shaft, wherein the seal separates the first cavity from the second cavity so that the first cavity is not disposed in fluid communication with the second cavity;

wherein the end cap cover defines an annular channel therein, and further wherein the seal is disposed within the annular channel; and

a fluid disposed in contact with the sector shaft and the rack ball nut within the second cavity;

wherein the fluid is not disposed within the first cavity and does not exert hydraulic pressure on the proximal end so that each of the plurality of gear teeth is spaced apart from a respective one of the plurality of cogs as the steering wheel rotates from the on-center position to the off-center position;

wherein a center one of the plurality of gear teeth meshes with a center one of the plurality of grooves to define a first gap having a first thickness between the center one of the plurality of gear teeth and one of the plurality of cogs when the steering wheel is disposed in the on-center position; and

wherein an outer one of the plurality of gear teeth meshes with an outer one of the plurality of grooves to define a second gap having a second thickness that is greater than the first thickness between the outer one of the plurality of gear teeth and an outer one of the plurality of cogs when the steering wheel is disposed in the off-center position.

2. The steering system of claim **1**, wherein the fluid is not disposed within the first cavity when the steering wheel is disposed in the on-center position.

3. The steering system of claim **1**, wherein the fluid is not disposed within the first cavity when the steering wheel is disposed in the off-center position.

4. The steering system of claim **1**, wherein the fluid is not flowable from the second cavity to the first cavity so that each of the plurality of gear teeth is spaced apart from a respective one of the plurality of cogs as the steering wheel rotates from the on-center position to the off-center position.

5. The steering system of claim **1**, wherein the fluid is not flowable from the second cavity to the first cavity so that the center one of the plurality of gear teeth meshes with the center one of the plurality of grooves as the steering wheel rotates from the off-center position to the on-center position.

6. The steering system of claim **1**, wherein the steering wheel rotates between the on-center position and the off-center position to translate the rack ball nut along an axis that is substantially perpendicular to the central longitudinal axis and thereby rotate the sector shaft about the central longitudinal axis.

7. The steering system of claim **1**, further including a nut threadably matable with the lash adjuster and abuttable with the end cap cover, wherein the end cap cover is not rotatable about the central longitudinal axis.

8. The steering system of claim **7**, wherein the lash adjuster is rotatable with respect to the end cap cover to translate the washer along the central longitudinal axis away from the proximal end, compress the resilient member, and thereby decrease the first thickness.

9. The steering system of claim **7**, wherein the nut, the end cap cover, the seal, the lash adjuster, and the resilient member together suspend the sector shaft along the central longitudinal axis adjacent to the plurality of cogs to thereby minimize the first thickness when the steering wheel is disposed in the on-center position, and maintain the second thickness when the steering wheel is disposed in the off-center position.

10. A steering system for a vehicle, the steering system comprising:

a steering wheel rotatable between an on-center position and an off-center position;

a sector shaft having a plurality of gear teeth each protruding therefrom along a respective one of a plurality of gear axes, wherein the sector shaft has a proximal end defining a bore therein and is rotatable about a central longitudinal axis that is substantially perpendicular to each of the plurality of gear axes as the steering wheel rotates between the on-center position and the off-center position;

a rack ball nut having a plurality of cogs extending therefrom and defining a plurality of grooves therebetween, wherein each of the plurality of gear teeth is matable with a respective one of the plurality of grooves;

a lash adjuster translatable within the bore along the central longitudinal axis;

a resilient member disposed within the bore;

a washer sandwiched between the resilient member and the lash adjusters;

an end cap cover abutting the lash adjuster and spaced apart from the sector shaft to define a first cavity between the end cap cover and the sector shaft;

a housing abutting the end cap cover and spaced apart from the sector shaft to define a second cavity between the housing and the sector shaft;

a seal surrounding and abutting the sector shaft, wherein the seal separates the first cavity from the second cavity so that the first cavity is not disposed in fluid communication with the second cavity; and

a fluid disposed in contact with the sector shaft and the rack ball nut within the second cavity;

wherein the fluid is not disposed within the first cavity and does not exert hydraulic pressure on the proximal end so that each of the plurality of gear teeth is spaced apart from a respective one of the plurality of cogs as the steering wheel rotates from the on-center position to the off-center position;

wherein a center one of the plurality of gear teeth meshes with a center one of the plurality of grooves to define a first gap having a first thickness between the center one of the plurality of gear teeth and one of the plurality of cogs when the steering wheel is disposed in the on-center position, and

wherein an outer one of the plurality of gear teeth meshes with an outer one of the plurality of grooves to define a second gap having a second thickness that is greater than

the first thickness between the outer one of the plurality of gear teeth and an outer one of the plurality of cogs when the steering wheel is disposed in the off-center position.

11. The steering system of claim **10**, further including a nut threadably matable with the lash adjuster and abuttable with the end cap cover, wherein the end cap cover is not rotatable about the central longitudinal axis.

12. The steering system of claim **11**, wherein the lash adjuster is rotatable with respect to the end cap cover to translate the washer along the central longitudinal axis away from the proximal end, compress the resilient member, and thereby decrease the first thickness.

13. The steering system of claim **11**, wherein the nut, the end cap cover, the seal, the lash adjuster, and the resilient member together suspend the sector shaft along the central longitudinal axis adjacent to the plurality of cogs to thereby minimize the first thickness when the steering wheel is disposed in the on-center position, and maintain the second thickness when the steering wheel is disposed in the off-center position.

14. The steering system of claim **10**, wherein the steering wheel rotates between the on-center position and the off-center position to translate the rack ball nut along an axis that is substantially perpendicular to the central longitudinal axis and thereby rotate the sector shaft about the central longitudinal axis.

15. The steering system of claim **10**, wherein the fluid is not flowable from the second cavity to the first cavity.

16. A vehicle comprising:

an axle;

a plurality of wheels each rotatable about the axle; and

a steering system configured for pivoting the axle to thereby steer the plurality of wheels, the steering system including:

a steering wheel rotatable between an on-center position and an off-center position;

a sector shaft having a plurality of gear teeth each protruding therefrom along a respective one of a plurality of gear axes, wherein the sector shaft has a proximal end defining a bore therein and is rotatable about a central longitudinal axis that is substantially perpendicular to each of the plurality of gear axes as the steering wheel rotates between the on-center position and the off-center position;

a rack ball nut having a plurality of cogs extending therefrom and defining a plurality of grooves therebetween, wherein each of the plurality of gear teeth is matable with a respective one of the plurality of grooves;

a lash adjuster translatable within the bore along the central longitudinal axis;

a resilient member disposed within the bore;

a washer sandwiched between the resilient member and the lash adjuster;

an end cap cover abutting the lash adjuster and spaced apart from the sector shaft to define a first cavity between the end cap cover and the sector shaft;

a housing abutting the end cap cover and spaced apart from the sector shaft to define a second cavity between the housing and the sector shaft;

a seal surrounding and abutting the sector shaft, wherein the seal separates the first cavity from the second cavity so that the first cavity is not disposed in fluid communication with the second cavity; and

a fluid disposed in contact with the sector shaft and the rack ball nut within the second cavity;

wherein the fluid is not disposed within the first cavity and does not exert hydraulic pressure on the proximal end so that each of the plurality of gear teeth is spaced apart from a respective one of the plurality of cogs as the steering wheel rotates from the on-center position to the off-center position;

wherein a center one of the plurality of gear teeth meshes with a center one of the plurality of grooves to define a first gap having a first thickness between the center one of the plurality of gear teeth and one of the plurality of cogs when the steering wheel is disposed in the on-center position; and

wherein an outer one of the plurality of gear teeth meshes with an outer one of the plurality of grooves to define a second gap having a second thickness that is greater than the first thickness between the outer one of the plurality of gear teeth and an outer one of the plurality of cogs when the steering wheel is disposed in the off-center position.

17. The steering system of claim **16**, further including a nut threadably matable with the lash adjuster and abuttable with the end cap cover, wherein the end cap cover is not rotatable about the central longitudinal axis.

18. The steering system of claim **17**, wherein the lash adjuster is rotatable with respect to the end cap cover to translate the washer along the central longitudinal axis away from the proximal end, compress the resilient member, and thereby decrease the first thickness.

19. The steering system of claim **17**, wherein the nut, the end cap cover, the seal, the lash adjuster, and the resilient member together suspend the sector shaft along the central longitudinal axis adjacent to the plurality of cogs to thereby minimize the first thickness when the steering wheel is disposed in the on-center position, and maintain the second thickness when the steering wheel is disposed in the off-center position.

20. The steering system of claim **16**, wherein the steering wheel rotates between the on-center position and the off-center position to translate the rack ball nut along an axis that is substantially perpendicular to the central longitudinal axis and thereby rotate the sector shaft about the central longitudinal axis.

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